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There is a recent movement toward the electonic display of aeronautical charts for mission planning and navigation in military aircrat. With the installation of the Digital Moving Map System (DMS) in the AV-8B Harrier, the U.S. Navy has taken the first step toward the widespread use of electronic navigational charts in its aircraft. In order to maximize the benefits from these systems, a new map image database has been specifically designed to meet the requirements of the DMS. The Naval Oceanographic and Atmospheric Research Laboratory (NOARL) is creating a compressed aeronautical chart database by compressing and transforming scanned chart data into a format that is compatible with the aircraft DMS. Image compression techniques have been chosen to allow rapid decompression and display while maximizing image quality. Production of the database, which will be distributed by the Defense Mapping Agency (DMA) on Compact Disk - Read Only Memory (CDROM), began at NOARL in February of this year.

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THE COMPRESSED AERONAUTICAL CHART DATABASE: SUPPORT OF NAVAL AIRCRAFT'S DIGITAL MOVING MAP SYSTEMS

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ABSTRACT

There is a recent movement toward the electronic display of aeronautical charts for mission planning and navigation in military aircraft. With the installation of the Digital Moving Map System (DMS) in the AV-8B Harrier, the U.S. Navy has taken the first step toward the widespread use of electronic navigational charts in its aircraft. In order to maximize the benefits from these systems, a new map image database has been specifically designed to meet the requirements of the DMS. The Naval Oceanographic and Atmospheric Research Laboratory (NOARL) is creating a compressed aeronautical chart database by compressing and transforming scanned chart data into a format that is compatible with the aircraft DMS. Image compression techniques have been chosen to allow rapid decompression and display while maximizing image quality. Production of the database, which will be distributed by the Defense Mapping Agency (DMA) on Compact Disk - Read Only Memory (CDROM), began at NOARL in February of this year.

INTRODUCTION

NOARL has designed and constructed the Map Data Formatting Facility (MDFF) to develop a database of compressed, scanned, aeronautical charts for distribution to naval aircraft as a library of CDROMs. The source of the unprocessed chart imagery is Equal Arc Second (ARC) Digitized Raster Graphics (ADRG) data, which is distributed on CDROM by DMA. The MDFF transforms ADRG from DMA's ARC projection to the Model-IV Tessellated Spheroid (TS) projection, and then compresses the data by approximately 48:1. The result, known as the Compressed Aeronautical Chart (CAC) library, can be quickly sampled by an aircraft's Mission Planning System (MPS) and loaded into a DMS for display onboard the aircraft.

The first MPS and DMS were developed as part of a Night Attack System for the AV-8B Harrier aircraft (Goodwin and Shaw, 1987). The objectives of implementing the MPS are to provide pilots with increased mission planning, preflight simulation, and the capability to rapidly integrate reconnaissance photographs and chart updates into the mission database. The use of a navigational DMS in the cockpit has many advantages over the use of paper or filmstrip, including the enhancement of nighttime map readability, a decrease in the amount of "heads-down" time for the pilot, and continuous electronic update of the aircraft's position and heading.

The interface between the DMS and the pilot is provided by a 4.5 x 4.5 inch Cathode Ray Tube (CRT) display with a resolution of approximately 128 pixels per inch (figure 1). This system enables the pilot to display digital navigational chart images and overlays of threat, route, and target symbols.

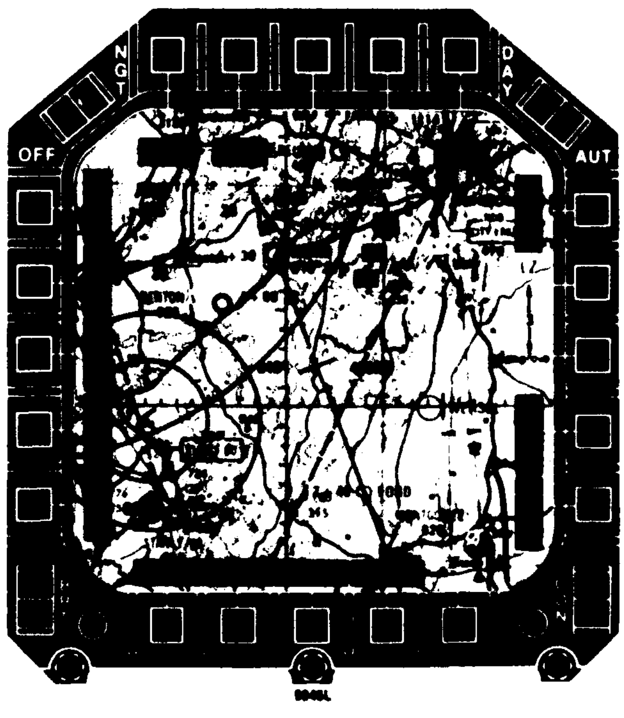

Figure 1. Digital Moving Map System Display.

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The DMS normally displays the chart data by keeping the location of the aircraft in the center of the display and moving the chart as dictated by the aircraft's navigation system, which is interfaced with the DMS. The pilot can switch between this so-called "track up" format and a "north up" format for easier reading of text and fine detail. The DMS also offers the capability of panning the entire map image stored in memory, look-ahead scrolling, zooming, and the ability to select and display one of up to six map scales: 1:50,000; 1:100,000; 1:250,000; 1:500,000; 1:1 million; and 1:2 million.

NOARL has been producing the CAC library in support of DMSs in the AV-8B Harrier and F/A-18 Hornet since February. By the end of this year, the CAC will also be supporting the V-22 Osprey, A-12 Avenger II, and the Navy's Tactical Aircraft Mission Planning System (TAMPS). The aircraft programs plan to replace all their paper and filmstrip charts with the DMS, particularly for night attack missions, since many of the paper charts are difficult to read at night or were not designed to be red-light readable (Lohrenz and Ryan, in press).

OVERVIEW OF CAC LIBRARY

The CAC is a standard, world-wide, seamless database of aeronautical chart imagery in six different scales, specifically designed to meet the requirements of aircraft DMS. These requirements include the following: the database must use a minimum of storage; it must be rapidly and easily decompressed and displayed; and it must be of optimal resolution (Lohrenz and Ryan, in press). The source of NOARL's CAC library is DMA's ADRG data. DMA produces ADRG by scanning navigational charts into a digital form and warping this scanned chart data into the ARC projection system (DMA, 1989). Source chart types and scales are listed in Table 1.

Table 1. Source Navigational Charts for ADRG.

SCALE	SOURCE CHARTS
1:50,000	Topographic Line Maps
1:100,000	(currently unavailable)
1:250,000	Joint Operations Graphics
1:500,000	Tactical Pilotage Charts
1:1,000,000	Operational Navigation Charts
1:2,000,000	Jet Navigation Charts

In June of this year, DMA will begin distributing NOARL's CAC data as a library of CDROMs. There are several advantages to using CDROM as the library's distribution medium. First, CDROMs and CDROM drives are relatively inexpensive. Second, with the establishment of the International Standard Organization (ISO) 9660 format, the CDROM has been established as a standard medium for data exchange. Finally, the disk itself is very light-weight, relatively rugged, and is not susceptible to changes in the magnetic field, all of which are particularly beneficial in field applications. Each CDROM will contain compressed chart imagery covering a particular geographical region in one of the six supported scales. Between 40 and 50 source ADRG CDROMs can be stored on one CAC CDROM as a seamless, compressed, transformed image. In addition, each CAC CDROM contains header information identifying the source ADRG CDROMs and paper charts, as well as compressed versions of the source legend images.

MDFF DATA PROCESSING

NOARL's processing of ADRG consists of four major phases: (1) transformation of map projection from ARC to TS; (2) color compression; (3) spatial compression; and (4) reformatting into an optical disk image.

ARC to TS Transformation

In the first phase, ADRG data is transformed from the ARC into the TS projection system, which has been specifically designed to support the DMS. The TS system was developed by the Sperry Defense Systems Division at Honeywell, Inc. Both the ARC and TS systems provide a rectangular coordinate system for the entire earth ellipsoid. The ARC system divides the earth into 18 bands of latitude, or zones, while TS divides the earth into 5 zones. Each zone in both systems is subdivided into sections (called "tiles" in ARC, and "segments" in TS), the number of which depends on the scale of the source map.

Each section has fixed latitude and longitude boundaries, and each pixel in the section is associated with a fixed latitude and longitude point. A pixel is represented by three bytes that define its red, green and blue (RGB) intensities.

An ARC tile corresponds to approximately 0.5 x 0.5 inches of the source map and consists of a 128 x [illegible] array of pixels. The pixel density of [illegible] image is therefore 256 pixels per [illegible] A TS segment corresponds to a 2 x 2 inch portion of the source map and consists of a 256 x 256 array of pixels. The pixel density of a TS image is therefore 128 pixels per inch, which is the resolution required by the DMS display. Thus, a 4:1 decrease in resolution accompanies the transformation from ARC to TS (from 256 to 128 pixels per inch along both the horizontal and vertical axes). The resulting TS segments are

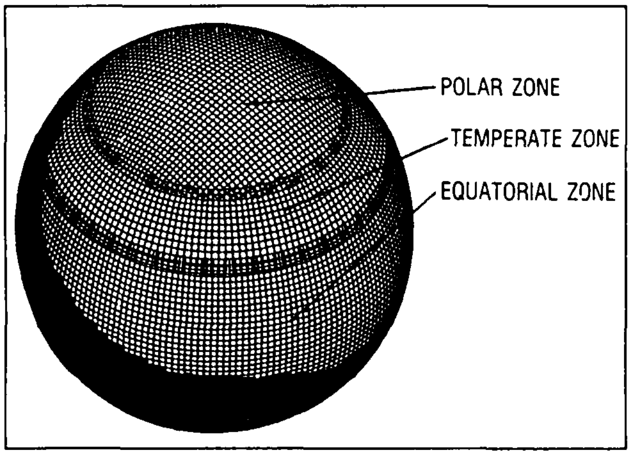

Figure 2. Model of Globe Overlaid with TS Segments. North Polar, North Temperate and Equatorial zones are visible; South Temperate and South Polar complete the five TS zones.

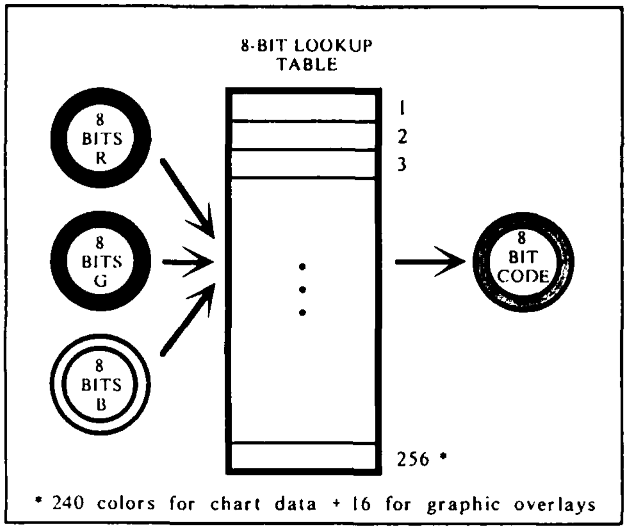

Figure 3. Color Compression of TS Image Data.

easily mosaicked to create a contiguous, seamless chart image. Figure 2 illustrates a model of the globe overlaid with TS segments, in which three of the five TS zones are annotated (North Polar, North Temperate, and Equatorial).

Color Compression

Color compression is achieved by subjecting the image data to a color vector quantization process that selects the closest match of 256 entries in a color palette to represent each pixel (figure 3). Several steps are involved in this process. First, a color map is created for a user-defined unit of scanned map data. A least-squares fitting technique is used to select 256 RGB combinations that will best represent that unit of map data. Then, for each pixel, the original 24 bits of RGB are replaced with an 8-bit code that represents one of the 256 RGB combinations, thereby compressing the image data by a factor of 3. Finally, a decompression color table is generated to convert the 8-bit codes back to the original (or close to the original) RGB values for CRT display.

Since the number of possible colors that can be used to represent each pixel in the image has been reduced from 2**24 (over 16 million) to 2**8 (256), information is lost in this step. However, the loss of information is merely perceived as a normalization of the map colors.

Spatial Compression

Spatial compression is achieved by applying a classified vector quantization process that replaces each 4-pixel block in the image with a 1-byte codeword from a 256-entry lookup table (figure 4). A codebook is generated from these codewords, reclassifying the image data using an average of 2 bits per pixel. A decompression codebook is also generated to convert the compressed pixel data back to the original image. The number of bits of information per pixel is thus decreased from 2**8 (256) to 2**2 (4) in this step, for a compression ratio of 4:1. The change in image quality is noticeable, but not significant. The exact method of determining the codewords that make up the compression codebook is proprietary to Sperry Defense Systems, the contractor that developed the compression algorithms and software.

Reformatting into Optical Disk Image

The final processing phase consists of reformatting the transformed, compressed data into an ISO-9660 optical disk image for replication onto a CDROM. Image data is contained in individual files, each corresponding to one segment in the TS map projection system, which in turn corresponds to a compressed 2 x 2 inch section of chart.

Studies are currently underway to precisely determine the storage requirements for each CDROM in the CAC library. Each CDROM's data contents (in terms of geographic areas and source DMA charts) are also being charted and indexed. In addition, the exact locations of all TS segments are being plotted globally for each supported scale. Results will be published in a future report.

DECOMPRESSION FOR DISPLAY

Decompression for display on the MPS is quick and easy. Each byte in the compressed image is used as an index into a double table-lookup operation: first spatial decompression

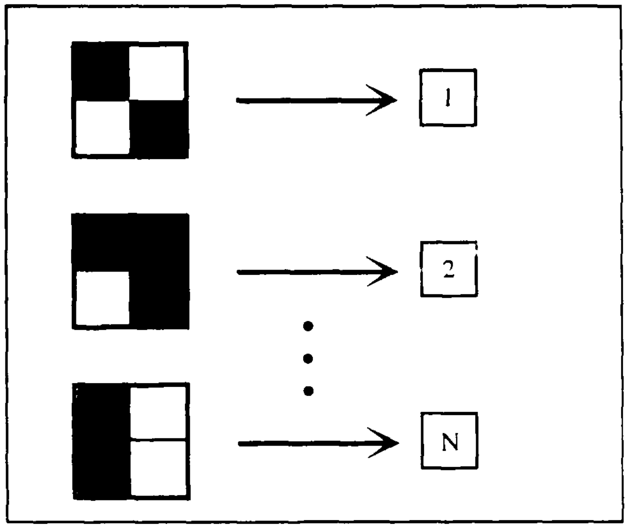

Figure 4. Spatial Compression of TS Image Data. Each 4-pixel block of data is examined and assigned one of 256 codewords, depending on the relative spatial pattern of the block. Illustrated are three sample patterns. The actual method of choosing the 256 "best" patterns to represent an entire image is proprietary to the Sperry Defense Systems Division at Honeywell, Inc.

is applied, then color decompression. Latitudinal and longitudinal boundaries of each compressed data file is encoded in the file name for easy identification and mosaicking. Apart from the necessary change in scale and resolution, image quality is not seriously compromised.

Spatial Decompression

The decompression codebook that was generated during spatial compression contains 256 sequential 4-byte codewords. Each codeword represents a 2 x 2 pixel square that is used to reconstruct the original image. The first byte corresponds to the upper-left pixel in the 2 x 2 square, the second to the upper-right, the third to the lower-left, and the fourth to the lower-right. Each byte in the compressed data contains an index into the codebook. Spatial decompression is accomplished by performing a lookup into the codebook: each byte of the compressed data is indexed into the codebook, and each of the resulting codeword's four bytes are then placed into the appropriate location in a 256 x 256 matrix representing the pixels of the reconstructed image.

In the lookup portion of spatial decompression, each byte of the compressed image data is treated as an unsigned integer from 0 to 255 and represents a particular codeword. The codewords are numbered from 0 to 255, and the bytes in the codebook are numbered from 0 to 1023. If a compressed data byte contains the value n, then the codeword represented by this value is located in byte positions 4N, 4N+1, 4N+2, and 4N+3. This lookup procedure is illustrated in Figure 5.

After a byte from the compressed data is used to index the appropriate codeword, the codeword's four bytes are placed in the 256 x 256 element matrix in unique positions determined by the byte's position in the compressed data sequence. If the rows and columns of the matrix are numbered from 0 to 255 and the compressed data bytes are numbered from 0 to 16383, then the Northwest (NW) byte of the codeword represented by byte number m is placed as follows:

row(m,NW) = [m - (m modulo 128)] / 64
col(m,NW) = (m modulo 128) *2

Similarly, the Northeast (NE), Southeast (SE), and Southwest (SW) bytes are placed as follows:

row(m,NE) = [m - (m modulo 128)] / 64
col(m,NE) = [(m modulo 128) *2] + 1

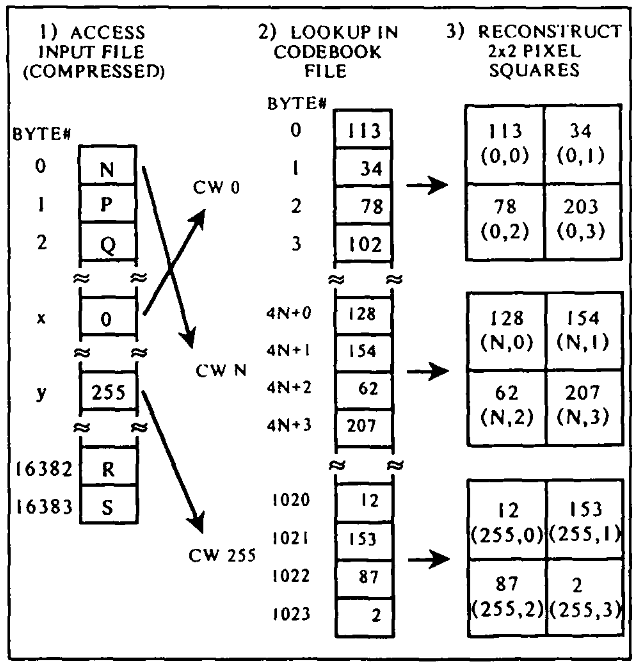

Figure 5. Spatial Decompression Method.
1) The compressed input file is accessed, and the codeword value (e.g., N) is extracted.
2) Lookup the N-th codeword from the codebook file, and access the byte values in positions 4N, 4N+1, 4N+2, and 4N+3.
3) Reconstruct the original (decompressed) 2 x 2 pixel square using the 4 values from codeword N: 4N+0 = upper left; 4N+1 = upper right; 4N+2 = lower left; 4N+3 = lower right.

row(m,SE) = {[m - (m modulo 128)] / 64} + 1
col(m,SE) = [(m modulo 128) *2] + 1

row(m,SW) = {[m - (m modulo 128)] / 64} + 1
col(m,SW) = (m modulo 128) *2

The result of spatial decompression is a 256 x 256 matrix of one-byte elements. Each byte may then used for color decompression.

Color Decompression

The RGB color palette consists of 256 three-byte codewords, 240 of which are used for the image data and 16 of which are reserved for graphic overlays and checksums. One byte of each codeword represents the red intensity level, another represents the green, and a third is blue. In color decompression, each byte resulting from spatial decompression is used as an index into the color palette. The codeword resulting from this lookup procedure consists of three bytes representing the RGB intensities for the particular pixel in the matrix. In the lookup procedure, each byte in the spatially decompressed matrix is treated as an unsigned integer from 0 to 239 and represents a particular codeword in the color palette. The codewords are numbered from 0 to 239, and the bytes in the color palette are numbered from 0 to 2047. A value of m in the spatially decompressed matrix refers to the codeword located in byte positions 2m+512 (red intensity), 2m+1 (green), and 2m+513 (blue). This lookup procedure is illustrated in Figure 6. RGB values range from 0 (no intensity) to 255 (maximum intensity).

The first 1024 bytes in the color palette file contain color values for day mode operations, while the last 1024 bytes contain the night mode palette. Currently, only one palette is required by the aircraft, so the day and night palettes are identical. Likewise, the color palette contains byte fields for both monochrome and RGB, although only RGB is currently required by the aircraft. The monochrome value for the m-th codeword is located in byte position 2m of the color palette file. Monochrome values in the file have been computed as follows:

Mono = (0.30 * R) + (0.59 * G) + (0.11 * B)

RECOMMENDED IMPROVEMENTS IN DMS DATA AND DISPLAY

While the CAC library adequately meets the immediate operational requirements of the AV-8B, it should be seen as a first-generation product with ample room for improvement. Indeed, there are some obvious, though unavoidable, deficiencies in its current presentation in the cockpit.

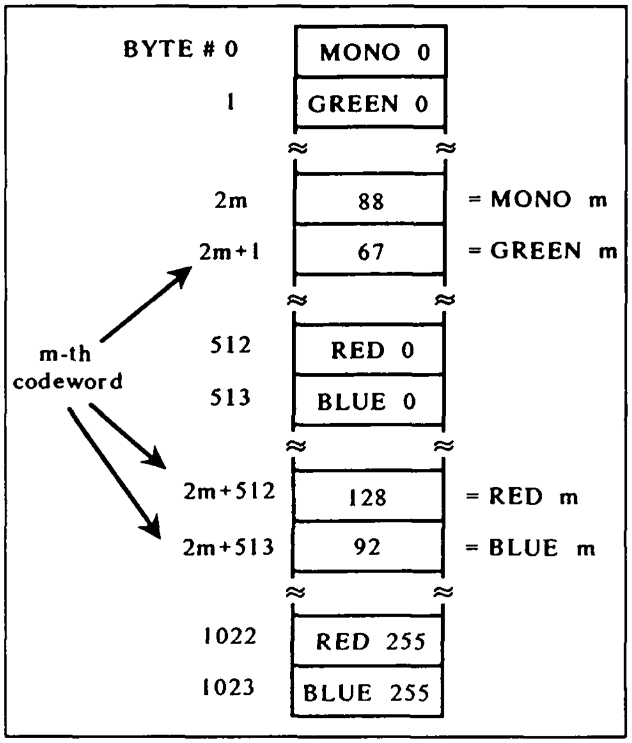

Figure 6. Color Decompression of CAC Image Data.

Deficiencies in the DMS Display

The first deficiency is less than adequate readability. This is a problem whenever there are fine lines present in the original paper chart, particularly contour lines and small text. While ADRG preserves these features adequately, the transformation from ARC to TS requires a significant loss of resolution, as mentioned earlier. A linear change of 1:2 is typical, so lines and text that are only two or three pixels in width are usually broken up in the subsampling process. As a result, these features are difficult to discern.

The second deficiency is clutter. While a pilot using a paper map has the ability to bring the map closer to discern cluttered features, a pilot looking at the DMS display does not have this luxury. Although the DMS has a zoom capability, test pilots have reported that merely enlarging pixel size does not clear up the clutter problem. This clutter is a characteristic of the original paper map that is carried over to the displayed map image.

The third problem is text that is displayed at a slant or upside-down. Most pilots prefer to fly with a track-up map display so that the map moves to reflect changes in the aircraft's heading. As a result, when the aircraft is flown in a non-northerly direction, text is displayed at a slant or upside-down. This problem is due to the fact that all features displayed on the map image are tied to the original paper map. That is, different feature types are not stored in separate overlays that could be displayed independently of one another. Although the pilot can switch the display between a track-up position and a north-up position to read text, the ability to read text upright while in the track-up mode would be a far superior option. If text were stored in a separate overlay, it would be possible to keep individual labels upright while tracking their relative locations on the moving map.

MDFF-Related Research Efforts

The CAC library is adequate for the near term. However, now is the time to begin defining the next generation of digital map databases, which must not only correct the previously mentioned deficiencies, but must also take full advantage of new digital map technology.

The MDFF team has established a research program focused on improving the pilot's moving map display. Three areas of study are being addressed: Alternative Methods of Map Image Compression, Base-Map Enhancement and Feature Extraction, and Graphic Display Enhancement (Shaw, et.al, 1989).

Alternative Methods of Map Image Compression are being examined for a number of reasons. First, the current spatial compression method used by the MDFF is proprietary to Sperry Defense Systems, the contractor that developed this method. It is therefore not government-owned. Second, we were interested in improving both the compression ratio and the quality of the output, decompressed, images.

Part of this study was completed last year. While exploring new processing techniques, researchers from NOARL and Tulane University yielded several promising new image compression ard classification schemes. The best map data compression was achieved using a two-phase process, in which pixel classification was followed by a lossless compression. A new compression scheme, Multi-Level Rooted Quadtree (MLRQ) coding, was developed by sorting binary map images using quadtrees. MLRQ coding was found to give good compression ratios for the color (multi-level) maps under consideration.

Two of the most promising classification techniques, K-means and Vector Quantization, were studied in detail. A neighborhood reclassification algorithm was also applied to eliminate isolated, misclassified pixels. Various high performance, lossless compression techniques were tried.

Initial results of this research were presented and published last year in the proceedings of the Institute of Electrical and Electronic Engineers (Jaisimha, et.al, 1989) and the Southeast Symposium on Systems Theory (Potlapalli, et.al, 1989). Follow-up work is underway this year to determine the best classification and compression methods to use in lieu of the Sperry proprietary method.

Base-Map Enhancement and Feature Extraction studies are underway to extract such features as roads, water, urban areas, and text from the scanned ADRG product, based on feature colors and patterns. The value of such a technique would be the resultant flexibility and control in displaying the data. For example, eliminating unneeded features would declutter the display, enabling the pilot to focus on mission-essential elements of the map and not be distracted by unnecessary information. Automated "decluttering" would also support further data compression.

Using feature extraction techniques, maps could be represented as a set of overlays that would be combined to produce a truly mission-specific composite map. The overlays could also be constructed from the original map's color separates at DMA, but these are not readily available. Instead, NOARL has proposed to use automated feature extraction methods to classify objects in a map image and relate them to particular overlays. The overlays could then be selectively combined in a Geographic Information System (GIS) environment.

Graphic Display Enhancement will be investigated for both ground station displays, used for flight planning, and cockpit displays, used for en route navigation. Assuming that ADRG data can be digitally decomposed into color or feature separates before being processed into CAC, DMS displays could be decluttered and enhanced. This work will identify display design possibilities for CAC and will consider the integration of other data products such as Vertical Obstruction Data, World Vector Shoreline data, Digital Terrain Elevation Data, Digital Feature Analysis Data, and multi-spectral imagery to generate more informative, mission-specific cockpit displays.

SUMMARY

NOARL's MDFF is creating a library of CAC data that has been specifically designed to support naval aircraft MPS and DMS. The CAC library, consisting of up to six scales of processed aeronautical chart imagery derived from ADRG, is stored as a library of CDROMs and distributed by DMA. The development and creation of this library is part of a NOARL effort to provide the fleet with system-specific, digital, Mapping, Charting and Geodesy (MC&G) products when the standard DMA products are unusable in their original form.

MDFF research efforts are underway to improve the current chart image compression techniques and to enhance and declutter the pilots' DMS displays. Progress has been made in these areas, but more work is necessary before the new methods can be applied.

More detailed information about the MDFF can be found in Shaw, et.al (1989); a complete product specification for the CAC library is contained in Lohrenz and Ryan (in press).

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